Appendix 13

Habitat Time Series Analysis

The purpose of this task was to develop habitat augmentation rules to avoid or mitigate both pulse and press disturbances (Niemi et al. 1990). The key criteria for these rules were developed by the determination of habitat stressor thresholds (HST) from their frequency of occurrence. Intra-annual rules should specify the magnitude of extreme habitat that should always be exceeded, as well as the magnitude and the duration of low-habitat events that are common in an average year. Inter-annual rules should define how frequently uncommonly low and long events could occur. We distinguished two duration types for rare events: persistent lows that can happen two or three years in a row (equivalent to a press disturbance); and catastrophic events that occur on the decadal scale (pulse stressors). All of these rules are organized by annual bio-periods.

To identify HST, habitat time series were developed and the habitat duration curves analyzed. Then we created uniform continuous under-threshold habitat-duration curves (UCUT-curves) modified from Capra et al. (1995). The curves evaluate durations and frequency of continuous events with habitat lower than a specified threshold. This is as a proportion of the entire study period, which is a sum of all days within one bioperiod in the hydrological record. As documented by Capra et al. (1995) the curves are good predictor of biological conditions.

Approximations of the threshold within the habitat template of the Souhegan River were developed from the simulated hydrograph and habitat rating functions (see Appendices 3 and 12). To create our UCUT curves (uniform continuous under-threshold habitat-duration curves), we first 'translated' the simulated hydrological time series (mean daily flows from 1947 – 1977) into a habitat time series (habitograph). Each incremental flow value was converted into a habitat value using a flow-habitat rating curve (representing habitat as a function of flow) for a bioperiod under the present habitat conditions.

Following Capra's procedure, a habitat event is defined as a continuous period in which the quantity of habitat (WUA, wetted usable area) stays under a predefined threshold. In our adaptation the UCUT curves describe the duration and frequency of events for a given bioperiod. Therefore the first step is to extract bioperiod data for each year from the habitographs (Figure 1).

In the second step the sum-length of all events of the same duration within bioperiods is computed as a ratio of a total duration of all bioperiods in the record (on the x-axis of the graph). The proportions are plotted as a cumulative frequency, i.e., the proportion of shorter periods is added to the proportions of all longer periods (Figure 2).

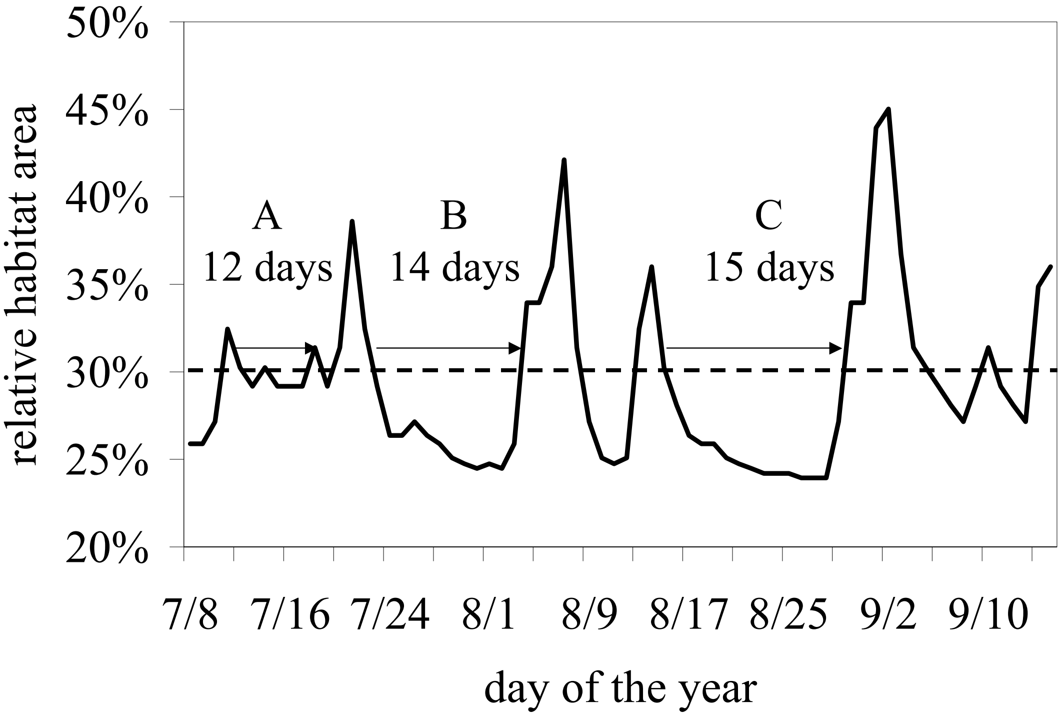


Figure 1: Schematic of UCUT curve computation for hypothetical suitable habitat time series.

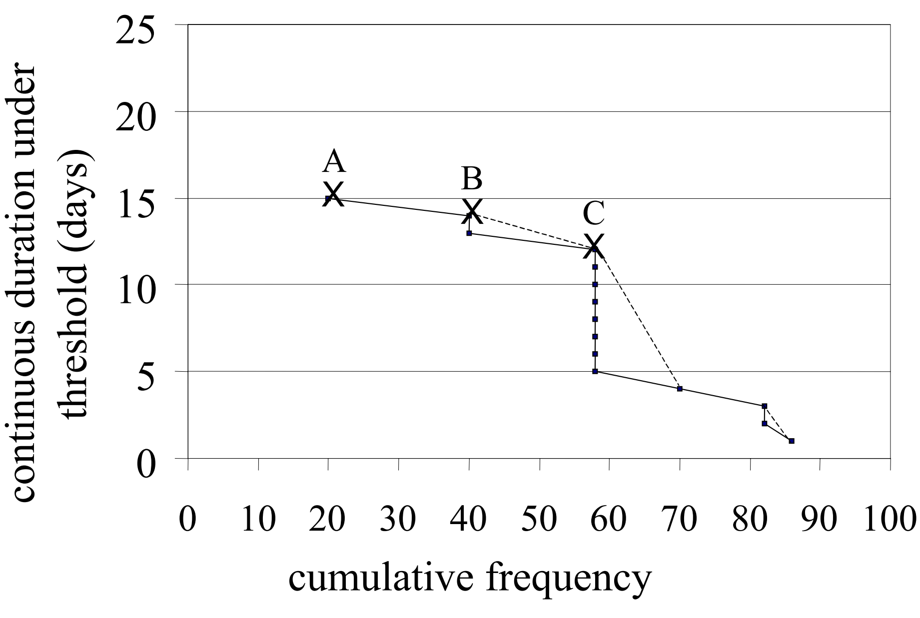


Figure 2: Differences between the CUT curves defined by Capra et al. 1995 (dashed line) and UCUTs (solid line).

For easier interpretation and calculation we further modified Capra's technique by including in the plot the continuous durations with 0% of cumulative increase (i.e., events that did not occur in the time series). For example, if the time series including the continuous durations of 14 and then 12 days, the CUT curve method will plot only those two points. In our method, we also plot the points for a cumulative duration of 13 days (equal to the one of 14 days), dropping the line first vertically and then joining it with the plot for 12 days (see Figure 2). To distinguish between the two approaches we called this adaptation uniform continuous under-threshold (UCUT).

This procedure is repeated for the entire set of thresholds with constant increments. The magnitude of the habitat increments between the thresholds is selected on an iterative basis, i.e., changing the increments until a clear pattern can be recognized. We look here for specific regions with a higher or lower concentration of the curves on the plot that would correspond with *rare, critical, and common* events. We also contrast this with the inflection points on the habitat duration curve developed for the same bioperiod. For rearing and growth (R&G) bioperiod the threshold with less than 45% exceedance probability is considered to demarcate *common* events. We then search for two inflection points on the duration curve in the proximity of 90% exceedance and investigate if those also stand out on the UCUT diagram.

Once the three threshold levels were identified we located the longest common or allowable durations from inflection points on the UCUT curves. These durations demarcated the beginning of persistent low habitat. The shortest of uniquely long durations appearing on the decadal scale are defined as catastrophic durations and are accompanied by their frequency of occurrence.

To develop habitat time series, the habitat rating curves described above are applied to simulated flow time series as developed for specific reaches. Figure 6 in the main report shows the locations of the gauges that were used to represent flow in a reach. Due to the limited number of flow observation at some gauges (caused by floods that damaged most of the gauges), the flow readings of neighboring gauges were lumped in pairs to provide a more robust representation of flows in a reach. Due to the fact that not all species or life stages are sensitive to flow changes in the habitat use, only rating curves that indicated such habitat were selected for the development of habitat time series. During the R&G and resident-species spawning seasons the preference was to choose the Generic Resident Adult Fish (GRAF) as the indicator. Only if the GRAF rating curve did not display any changes with flow or if other species were much more flow dependent were rating curves for individual species or the young-of-the-year (YOY) life stage used. During the R&G bioperiod the Habitat Duration Curve (HDC) and UCUT curves were computed for selected indicator species in every reach using a time series from neighboring flow gauges.

The spawning models were less precise than those for the R&G season and during spawning bioperiods flows are usually higher than in summer. Therefore, to establish PISF criteria for these times the HDC and UCUTs were computed for the most flow-sensitive reach in a segment. For seasons or reaches where habitat information was insufficient, flow based time series analysis were applied.

Habitat UCUTs were not developed for the seasons in which habitat information was sparse or nonexistent for the fauna of interest (e.g., over-winter). Instead, for the over-winter bioperiod we evaluated negative run length (i.e., flow-based UCUTs) and derived criteria solely on these data, presuming again that the fauna have adjusted to the most common natural flow conditions.

Results

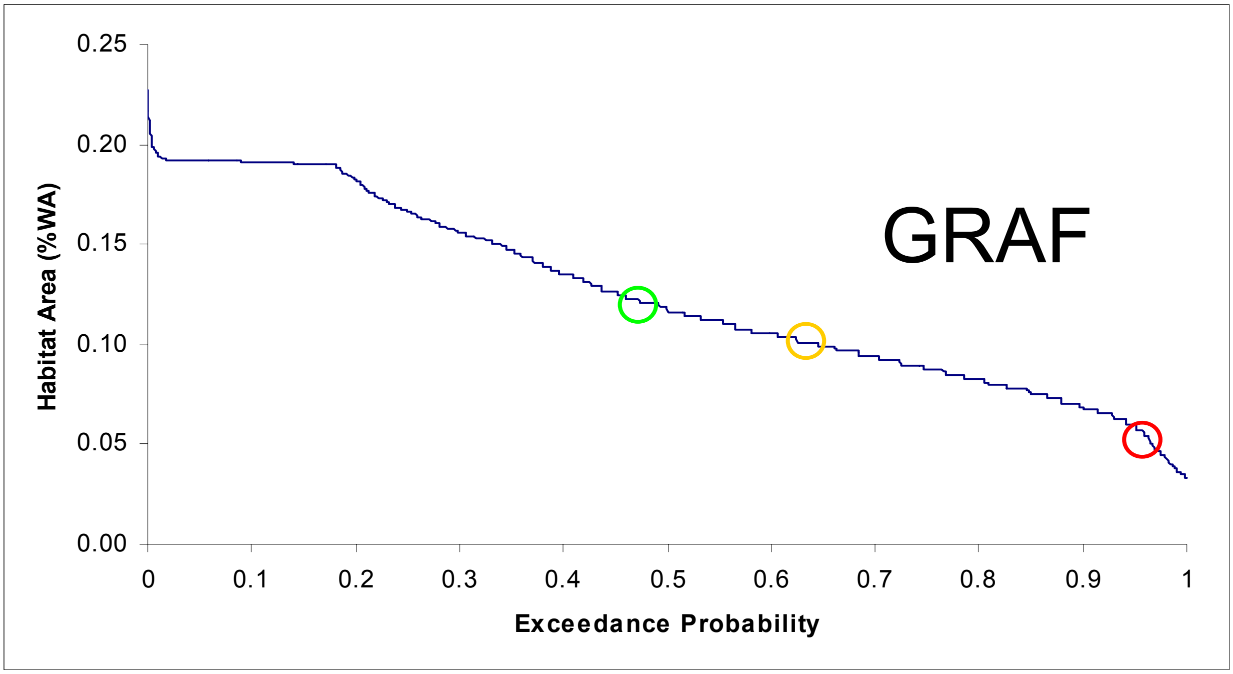
R& G bioperiod

Figures 3-5 present HDC and UCUT curves for reaches 1-3 in the Upper Souhegan River. In reach 1(Figure 3) there is a clear inflection point on the HDC for *rare* habitat conditions with 95% of exeedance interval and 7% WA of GRAF habitat threshold. The UCUT curves show dramatic increase of frequency when the threshold moves to 9% WA. The *common* threshold is identified with 13% WA and 45% exceedance probability.

The determination of longest common duration for *rare* habitat events was difficult and we selected the lowest of the two inflection points corresponding with 5 days. The catastrophic duration begins where the curve moves very close to the x-axis and was selected with 32 days. The UCUT for the *critical* event has a more pronounced inflection point at 15 days and catastrophic duration of 35 days. For the *common* level the inflection points were estimated with 30 days for common durations and 42 days for a catastrophic duration.

In reach 2 (Figure 4) there is a clear inflection point on the HDC for *rare* habitat conditions with 98% of exeedance interval and 14% WA of GRAF habitat threshold. The UCUT curves show a dramatic increase of frequency when the threshold moves to 15% WA. The *common* threshold is identified with 20% WA and 42% exceedance probability.

Again, the determination of longest common duration for *rare* habitat events was difficult and we selected the lowest of the two inflection points corresponding with 5 days. The catastrophic duration begins where the curve moves very close to the x-axis and was selected with 10 days. The UCUT for a *critical* event has a pronounced inflection point at 15 days and catastrophic duration of 40 days. For the *common* level the inflection points are estimated with 30 days for common durations and 45 days for a catastrophic duration.



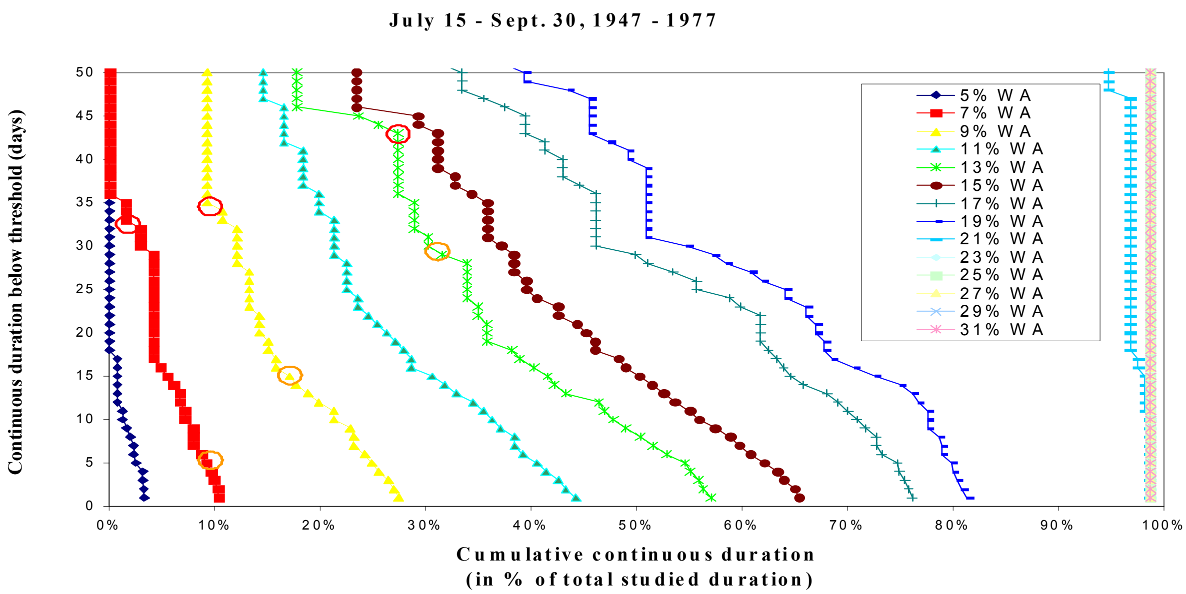


Figure 3: HDC and UCUT curves for Reach 1 R&G bioperiod.

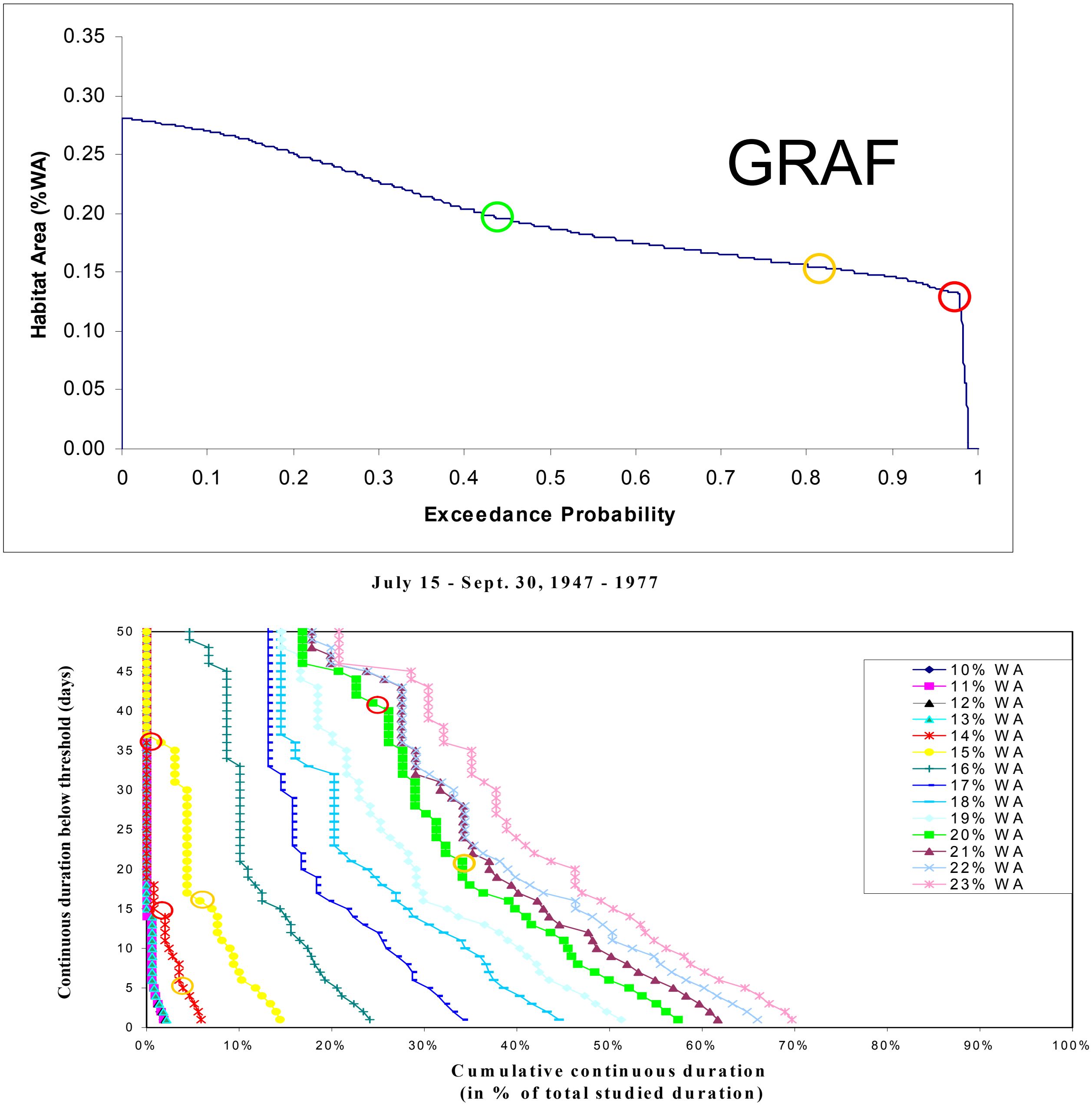
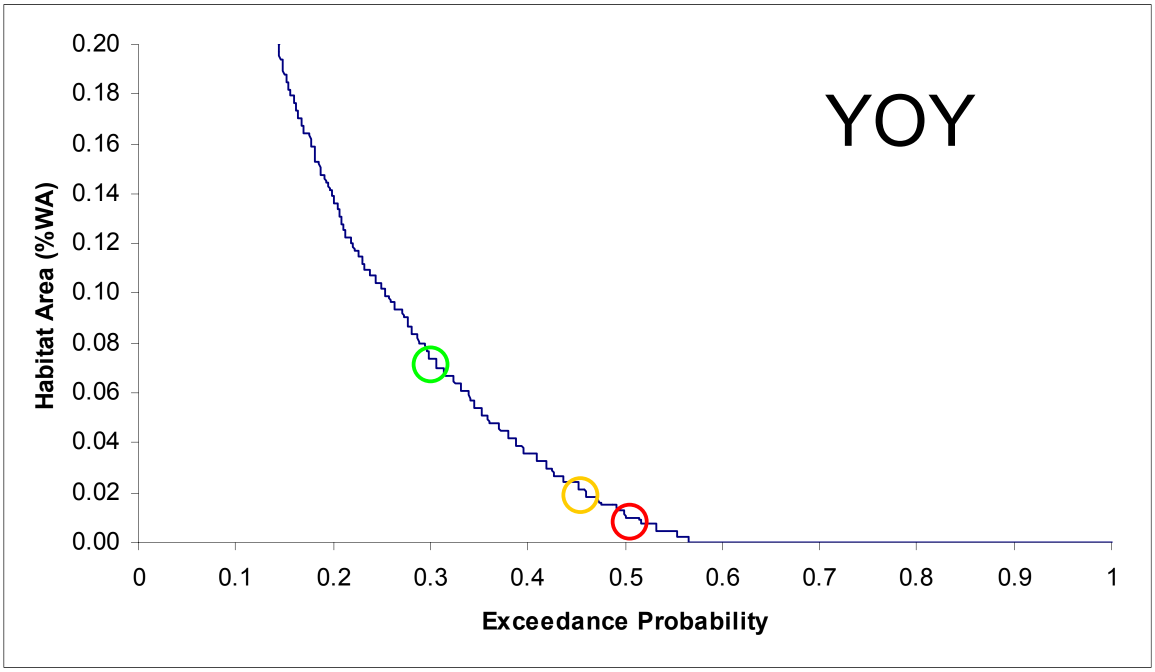


Figure 4: HDC and UCUT curves for Reach 2 R&G bioperiod.

In reach 3 (Figure 5) no inflection point can be observed on the HDC for *rare* habitat conditions. The habitat available for YOY is lower 1% level for 50% of time. The UCUT curves showed an increase in frequency when the threshold moves to 2% WA. Because the *critical* threshold already had an exceedance interval of 45%, the *common* threshold has been selected with 7% WA due to an increase of frequency of these events.

The inflection point for longest common duration was identified for a continuous duration of 10 days. The catastrophic duration begins with 35 days of habitat under this threshold. The UCUT for a *critical* event is identified as 17 days and a catastrophic duration of 40 days. For the *common* level the inflection points were estimated with 30 days for common durations and 45 days for a catastrophic duration.



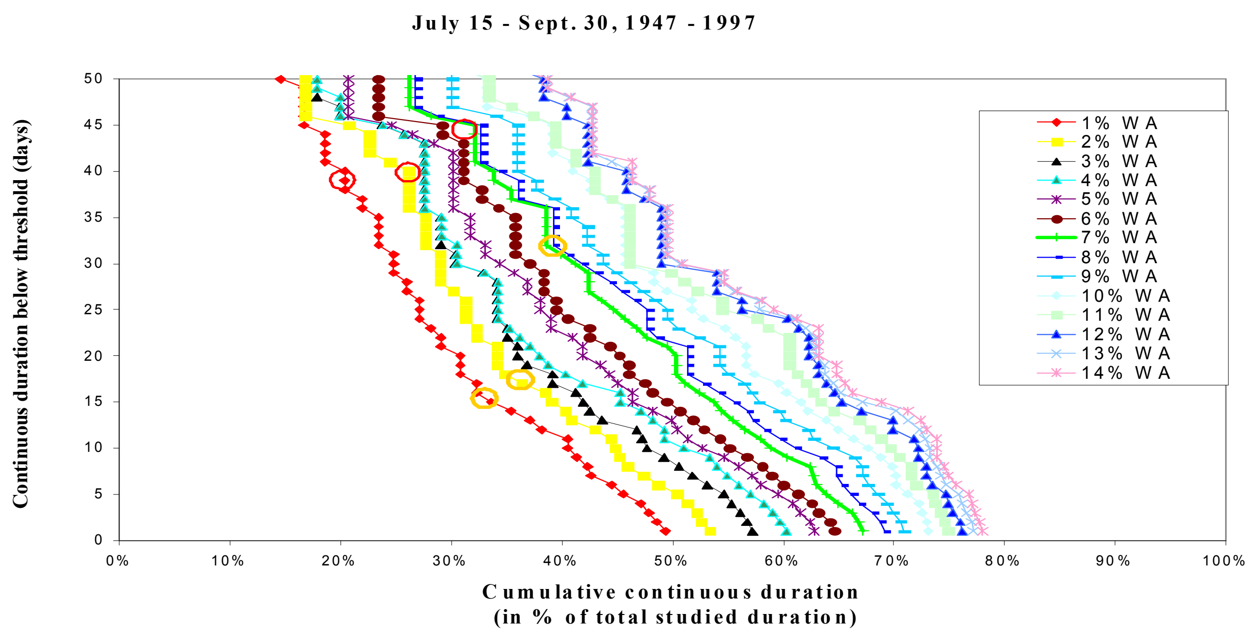
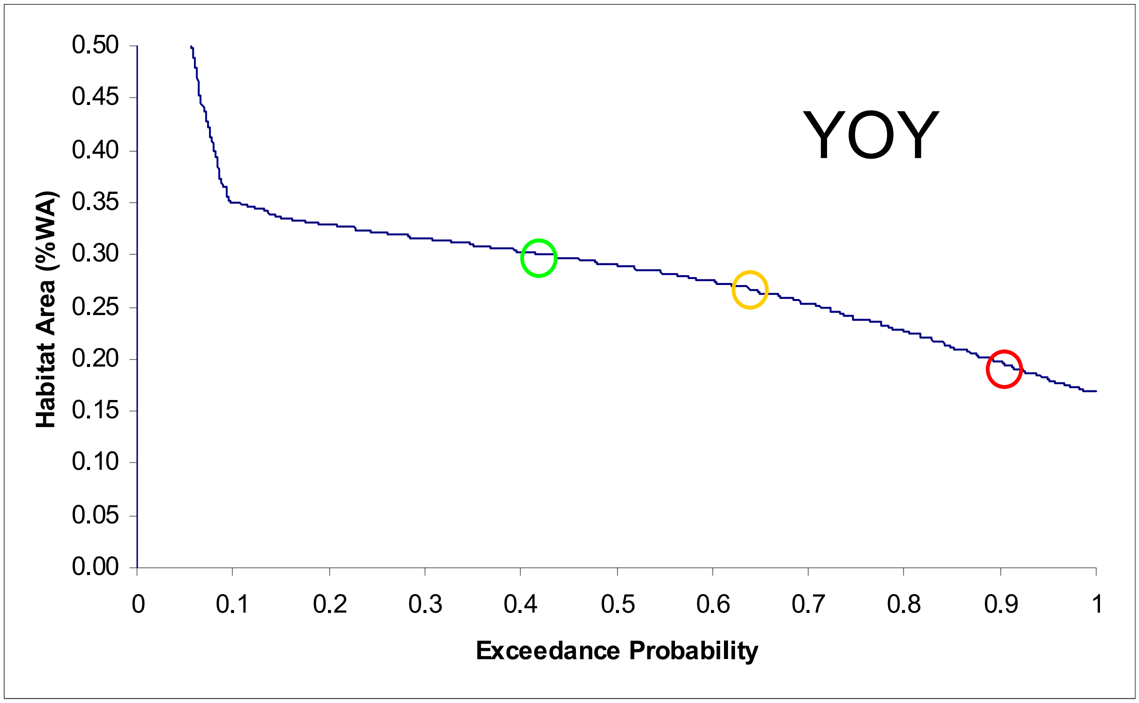


Figure 5: HDC and UCUT curves for Reach 3 R&G bioperiod.

Figures 6-9 present HDC and UCUT curves for reaches 4-7 in the Upper Souhegan River. In reach 4 (Figure 6) there is a no clear inflection point on the HDC for *rare* habitat conditions but the UCUT curve for 20% WA of YOY habitat threshold is distinct and was selected as the *rare* event demarcation. The frequency of events doubles when threshold is set to 22.5% WA. The *common* threshold was identified with 30% WA and 42% exceedance probability.



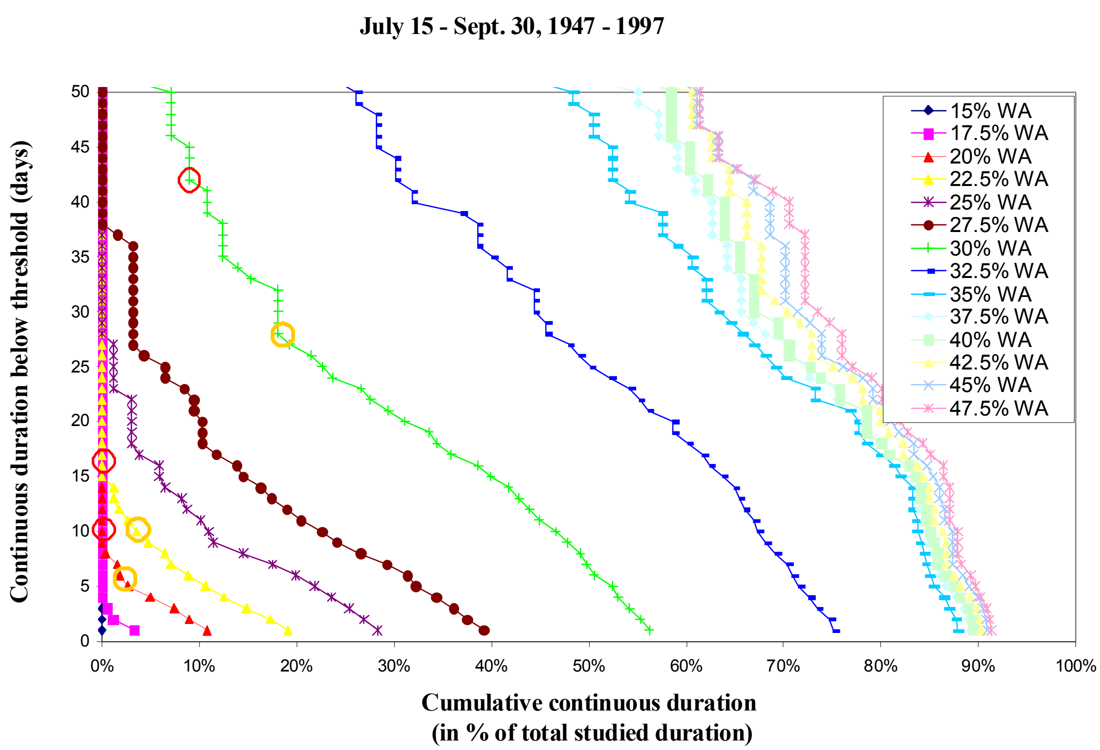


Figure 6: HDC and UCUT curves for Reach 4 R&G bioperiod.

The determination of longest common duration for *rare* habitat events was easy and corresponds with 5 days of continuous duration. The catastrophic duration begins where the curve moves very close to the x-axis and was selected at 10 days. The UCUT curves for a *critical* event has a more pronounced inflection point at 10 days and a catastrophic duration of 15 days. For the *common* level the inflection points were estimated with 28 days for common durations and 42 days for a catastrophic duration.

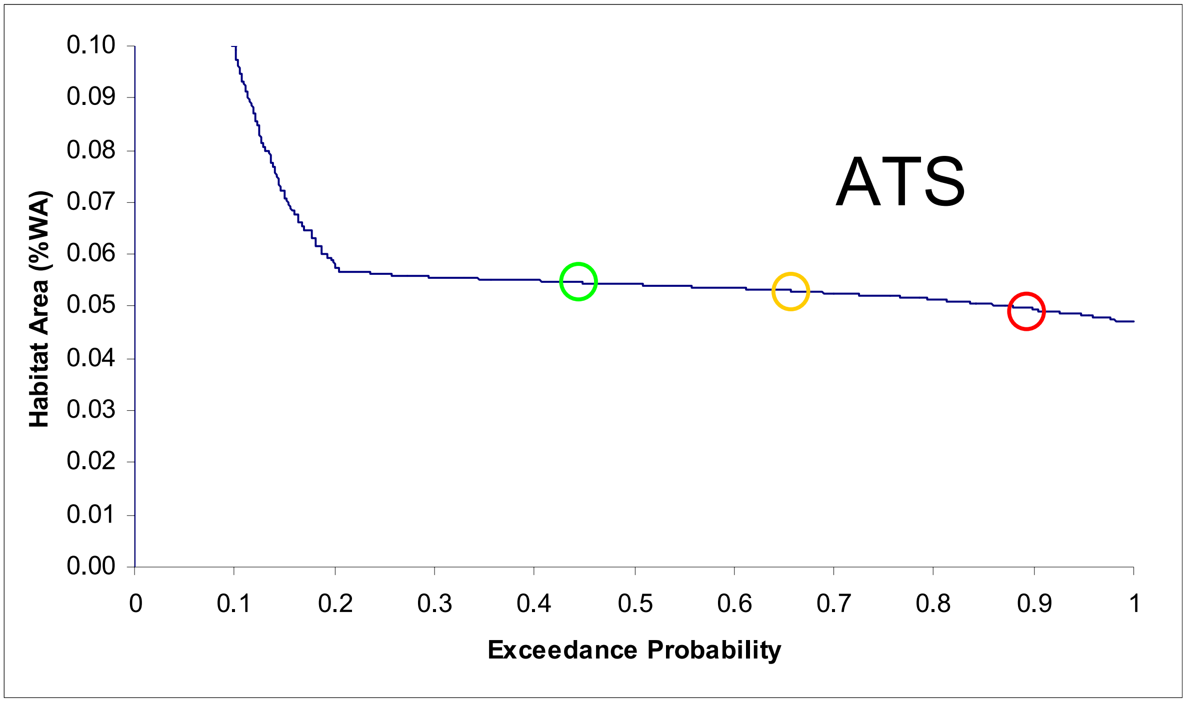
In reach 5 (Figure 7) there is a weak inflection point on the HDC for *rare* habitat conditions with 90% of exeedance interval and 5% WA of Atlantic salmon habitat threshold. The UCUT curves show a dramatic increase in frequency (double) when the threshold moves to 5.2%WA. The *common* threshold was identified with 5.5% WA and 42% exceedance probability.

The longest common duration for *rare* habitat was selected at 5 days although the inflection point is not very pronounced. The catastrophic duration begins where the curve moves very close to the x-axis and was selected at 10 days. The UCUT curve for a *critica*l event has a pronounced inflection point at 15 days and a catastrophic duration of 20 days. For the *common* level the inflection points were estimated with 30 days for common durations and 42 days for a catastrophic duration.

In reach 6 (Figure 8) there are very clear inflection points that can be observed on the HDC for *rare* habitat conditions under 20% of WA for GRAF and 95% exceedance probability. The UCUT curves show an increase in frequency by a third when the threshold moves to 25%WA. The *common* threshold is identified with 30% WA and 45% exceedance probability.

The inflection point for the longest common duration was identified for a continuous duration of 5 days. The catastrophic duration begins with 10 days of habitat under this threshold. The UCUT curve for a *critical* event is identified as 15 days and a catastrophic duration of 27 days. For the *common* level the inflection points are estimated with 20 days for common durations and 40 days for a catastrophic duration.

The HDC for reach 7 does not display a clear inflection point for *rare* habitat conditions but it can be clearly determined on the UCUT diagram with 18% WA of YOY. The frequency of events doubles when threshold is set to 19% WA. The *common* threshold is identified with 23% WA and 45% exceedance probability. The determination of longest common duration for *rare* habitat events was difficult and was selected at 5 days of continuous duration. The catastrophic duration begins where the curve moves very close to the x-axis and was selected at 10 days. The UCUT curve for a *critical* event has more pronounced inflection point at 15 days and a catastrophic duration of 27 days. For the *common* level the inflection points are estimated with 23 days for common durations and 40 days for a catastrophic duration.



July 15 - Sept. 30, 1947 - 1997

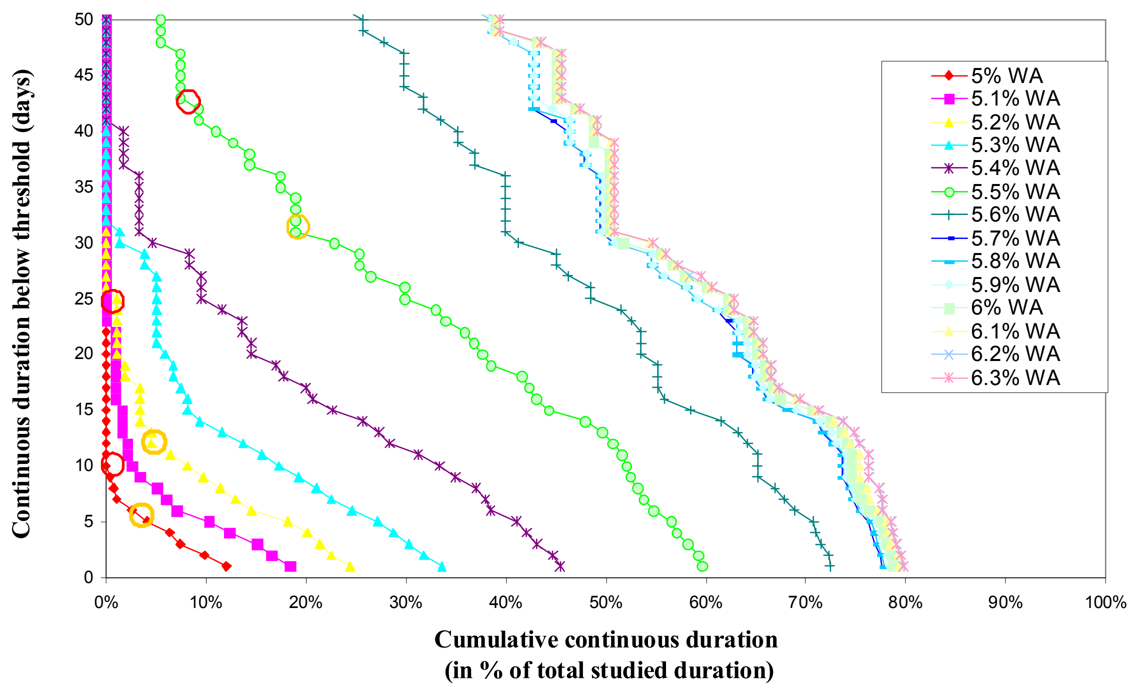
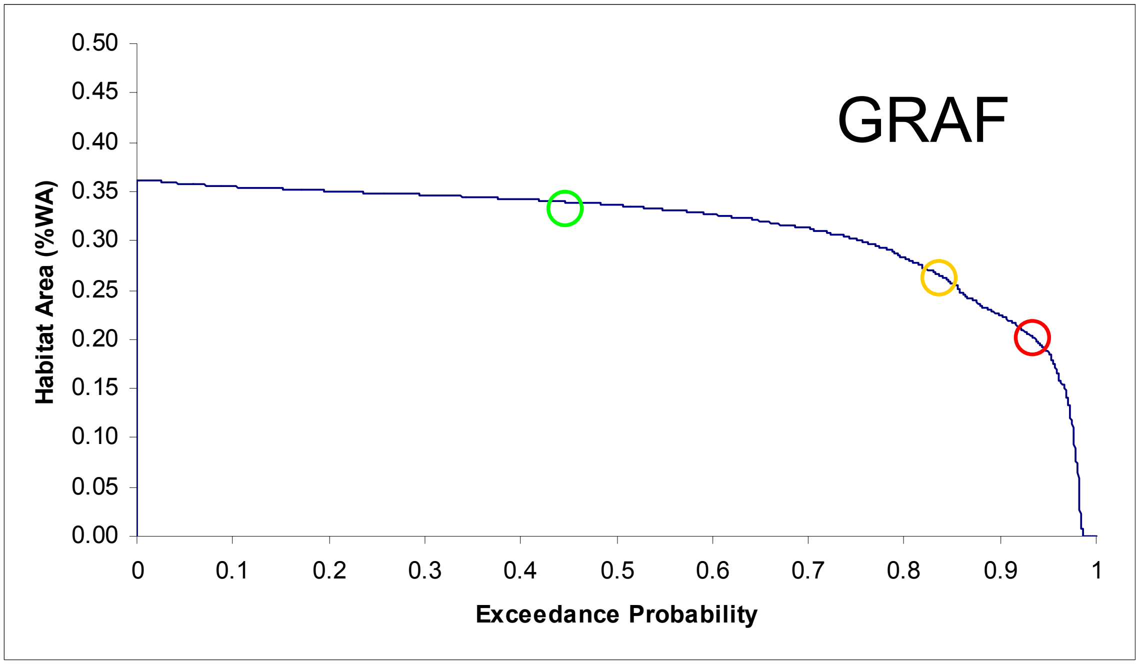


Figure 7: HDC and UCUT curves for Reach 5 R&G bioperiod.



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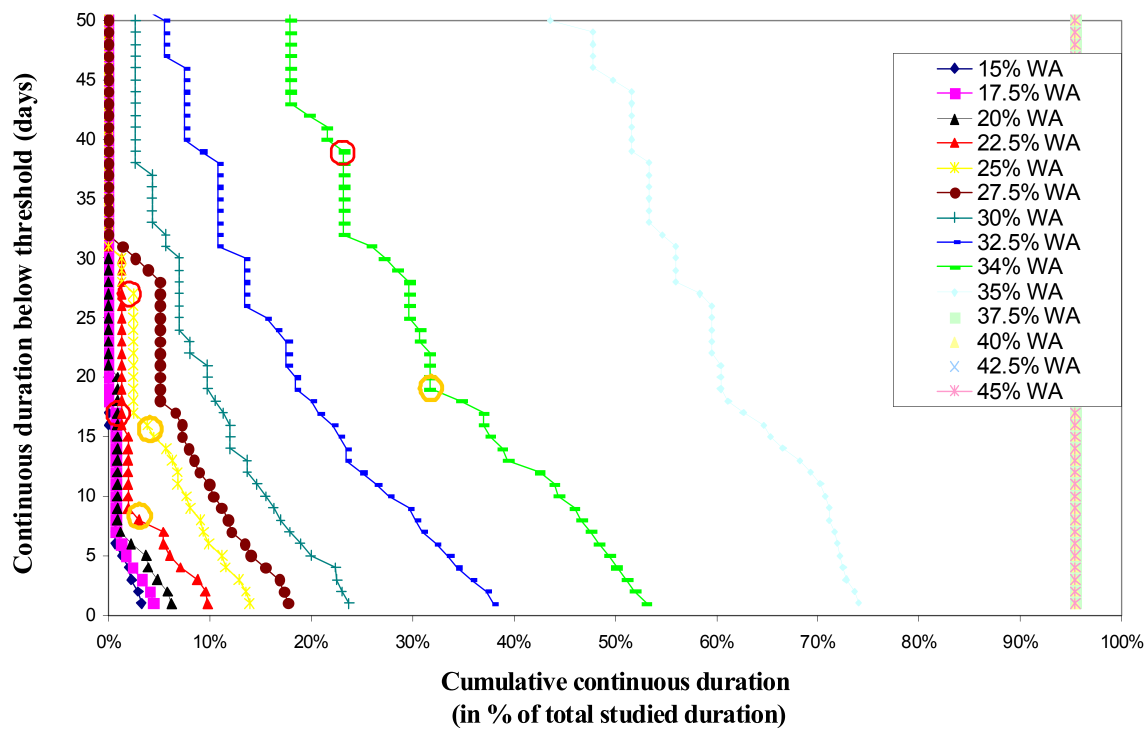
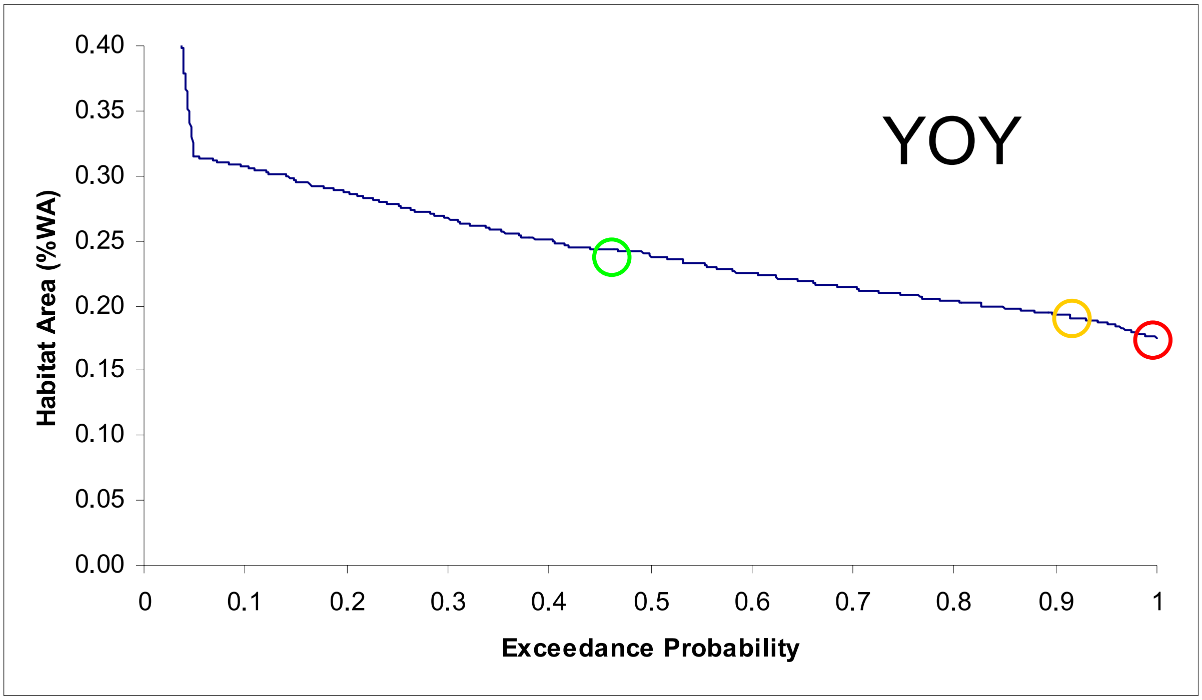


Figure 8: HDC and UCUT curves for Reach 6 R&G bioperiod.



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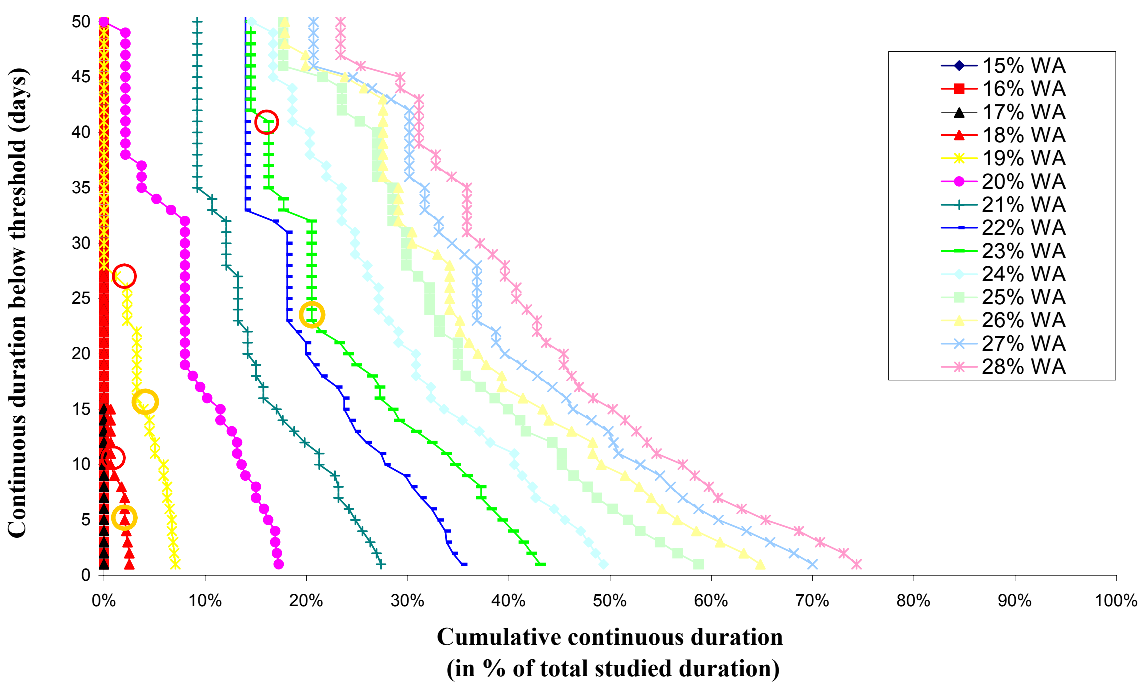


Figure 9: HDC and UCUT curves for Reach 7 R&G bioperiod.

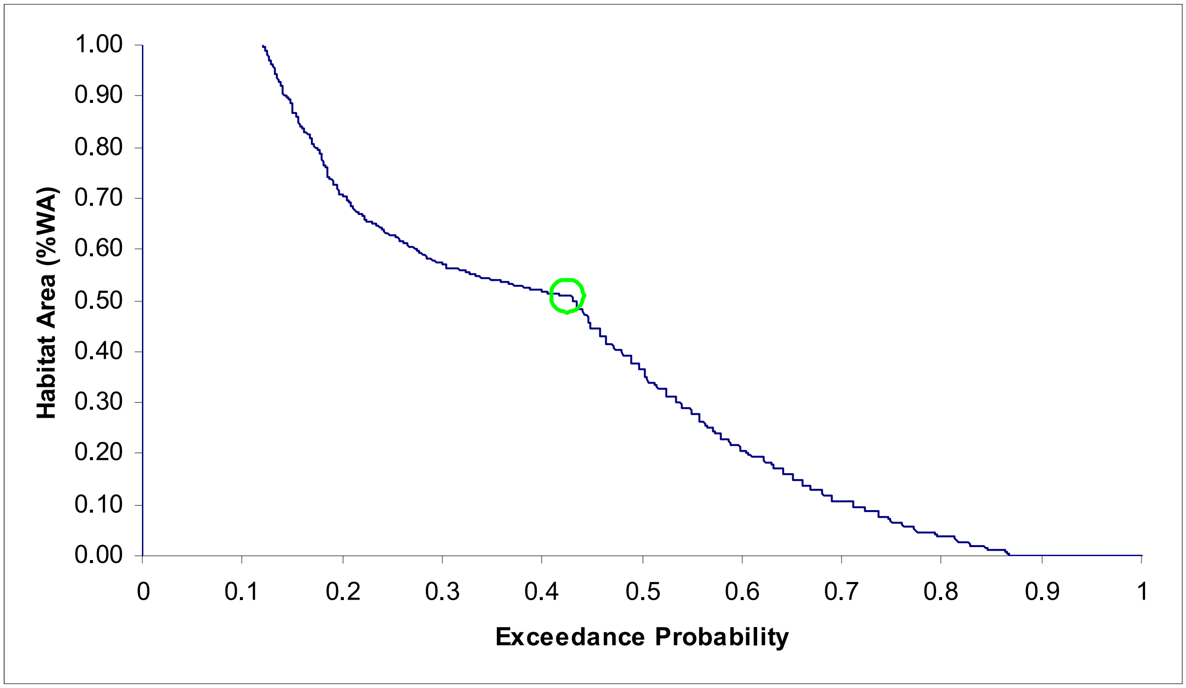
Atlantic salmon spawning

Figure 10 presents HDC and UCUT curves for reach 2, which represent Atlantic salmon spawning habitat in the Upper Souhegan River. In reach 2 there is no clear inflection point on the HDC for *rare* habitat conditions, but the UCUT curves show change in the frequency of habitat events when the threshold moves from 1% WA to 5% WA. The *common* threshold is identified by inflection point at the HDC with 50% WA.

We selected the lowest of the two inflection points corresponding with 10 days for allowable event durations. The catastrophic duration begins where the curve moves very close to the x-axis and was selected at 23 days. The UCUT curve for a *critical* event has a pronounced inflection point at 12 days and a catastrophic duration of 30 days. For the *common* level the inflection points were estimated with 30 days for common durations and 40 days for a catastrophic duration.

Figure 11 presents HDC and UCUT curves for reach 5, which represent Atlantic salmon spawning habitat in the Lower Souhegan River. In reach 5 there is no clear inflection point on the HDC for *rare* habitat conditions, but the UCUT curves show a change in frequency of habitat events when the threshold moves from 5% WA to 6% WA. The *commo*n threshold is identified by the inflection point at the HDC with 50% WA.

For *rare* habitat duration we selected 5 days for allowable event durations. The catastrophic duration begins where the curve moves very close to the x-axis and was selected at 10 days. The UCUT curve for a *critical* event has an inflection point at 12 days and a catastrophic duration of 30 days. For the *common* level the inflection points were estimated with 23 days for common durations and 40 days for a catastrophic duration.



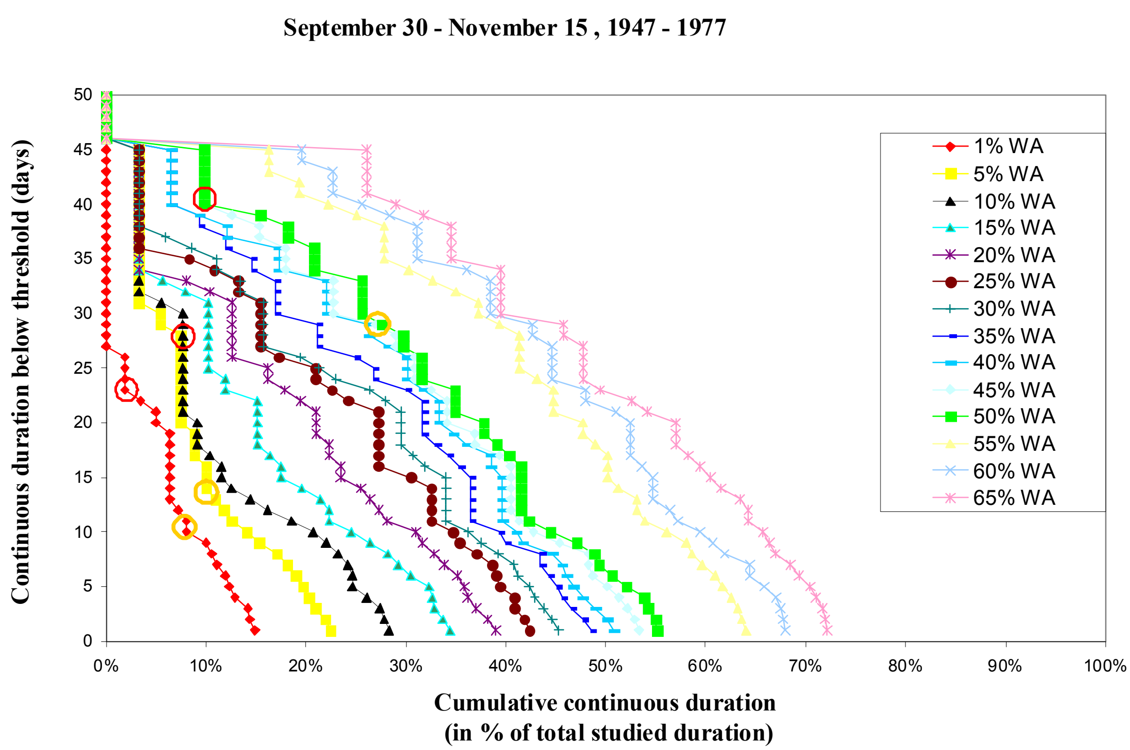
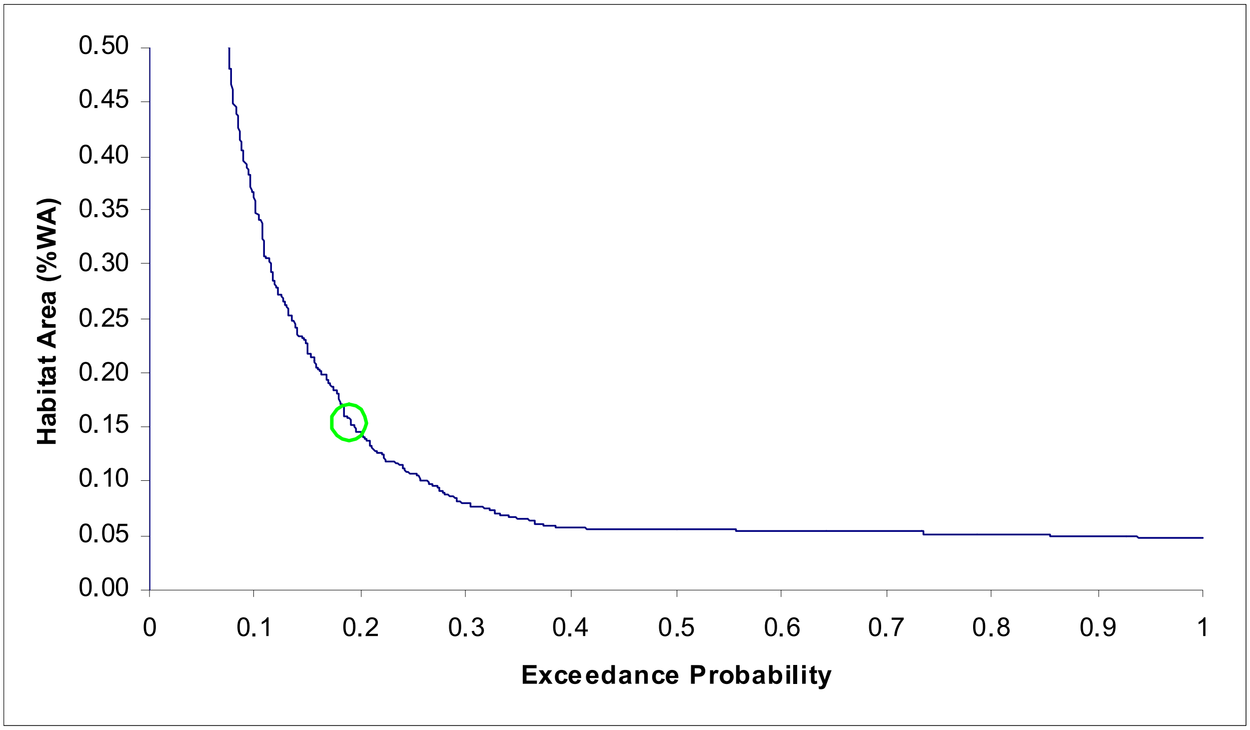


Figure 10: HDC and UCUT curves for Reach 2 Atlantic salmon spawning.



September 30 - November 15 , 1947 - 1977

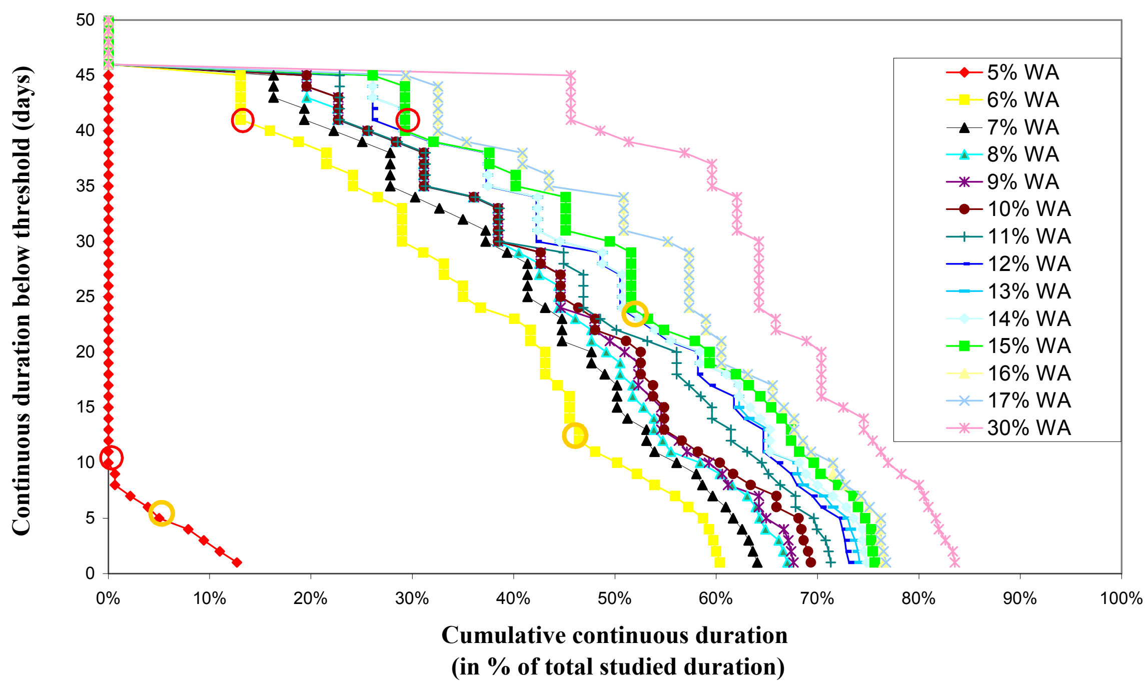
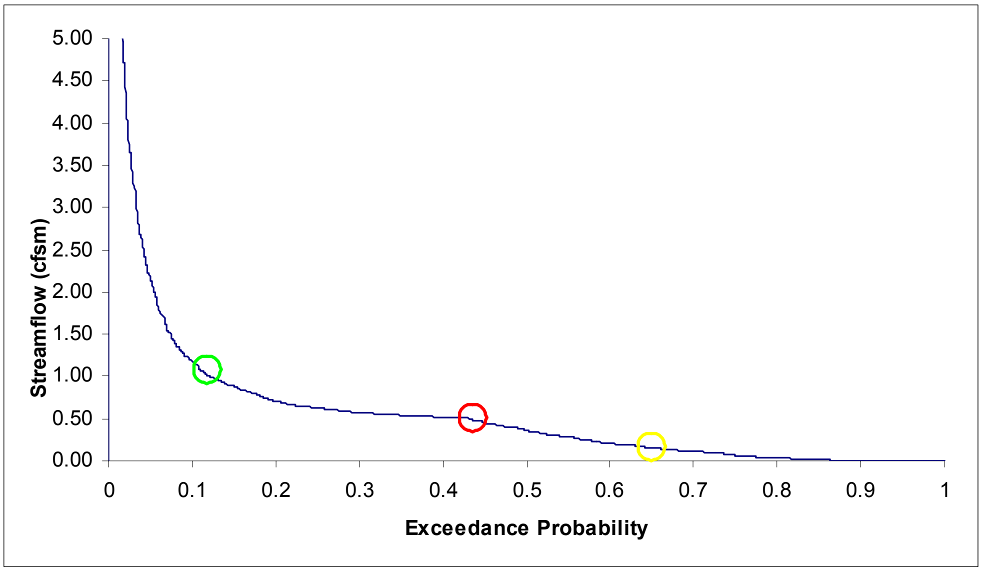


Figure 11: HDC and UCUT curves for Reach 5 Atlantic salmon spawning.

Overwintering

Figure 12 presents flow duration curve (FDC) and flow based UCUT curves for USGS gauge in Merrimack in the overwintering season. The inflection points allowed us to select *common* and *critical* thresholds. Events of flows lower than 0.3 cfsm happened for 1% of the time. There are hardly any inflection points visible on the UCUT curves. We attempted to identify common and catastrophic durations at 5 days and 10 days respectively for the *rare* threshold, 15 days and 30 days for the *critical* and 35 days and 50 days for the *common* threshold.



November 15- February 28 , 1947 - 1977

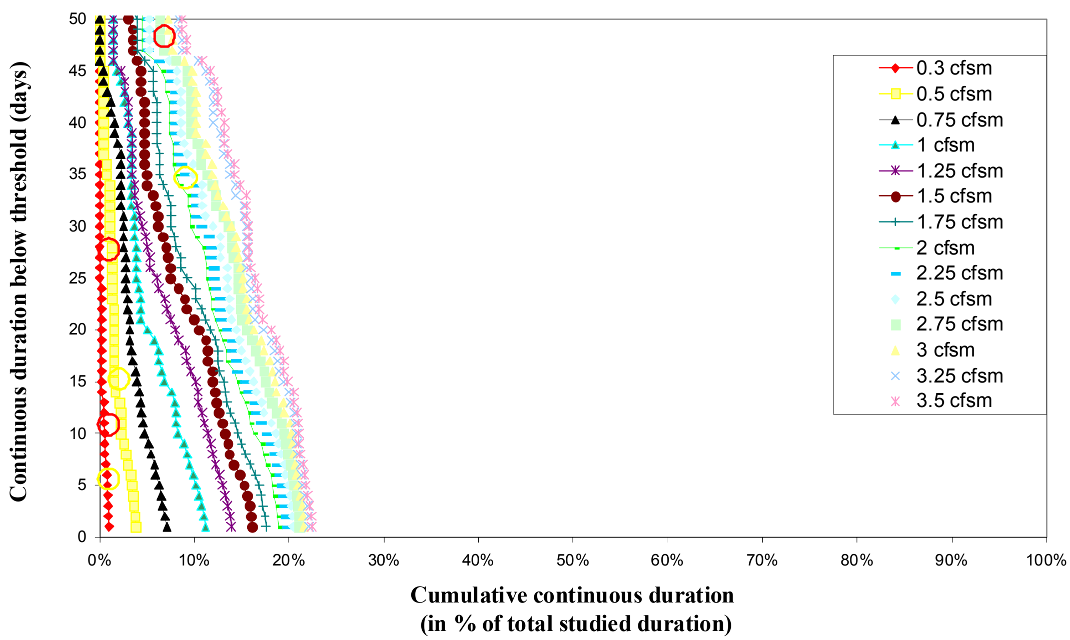
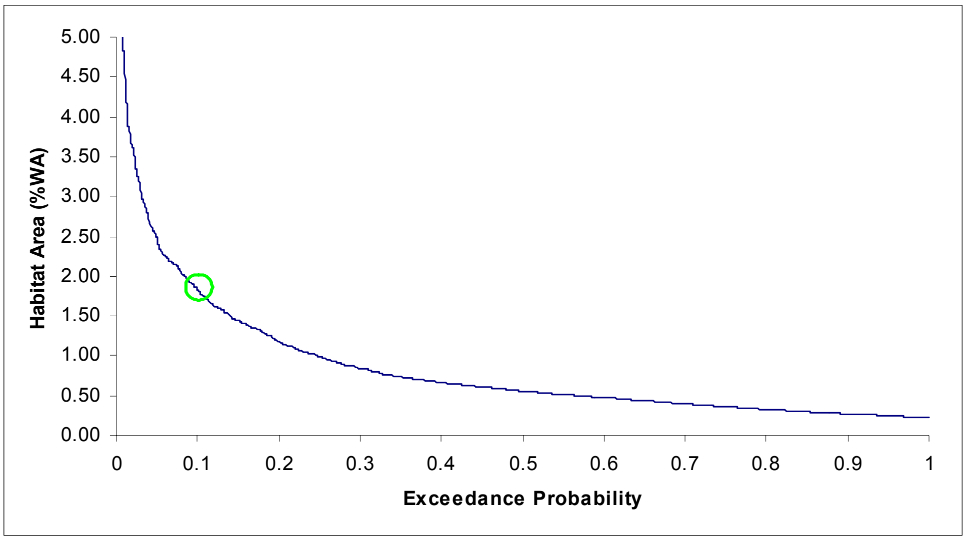


Figure 12: FDC and UCUT curves for overwintering bioperiod.

American shad spawning

Figure 13 presents HDC and UCUT curves for reach 2, which represent American shad spawning habitat in the Upper Souhegan River. In reach 2 there is no clear inflection point on the HDC for *rare* habitat conditions, but the UCUT curves show change in the frequency of habitat events when the threshold moves from 25% WA to 30% WA. The *common* threshold is identified by the inflection point at the HDC with 70% WA.

We selected 4 days for allowable habitat durations under *rare* thresholds. The catastrophic duration begins where the curve moves very close to the x-axis and was selected at 7 days. The UCUT for a *critical* event has a pronounced inflection point at 10 days and a catastrophic duration of 15 days. For *common* duration the inflection points are estimated with 25 days for the common level and 40 days for a catastrophic duration.



May 1-June 15 , 1947 - 1977

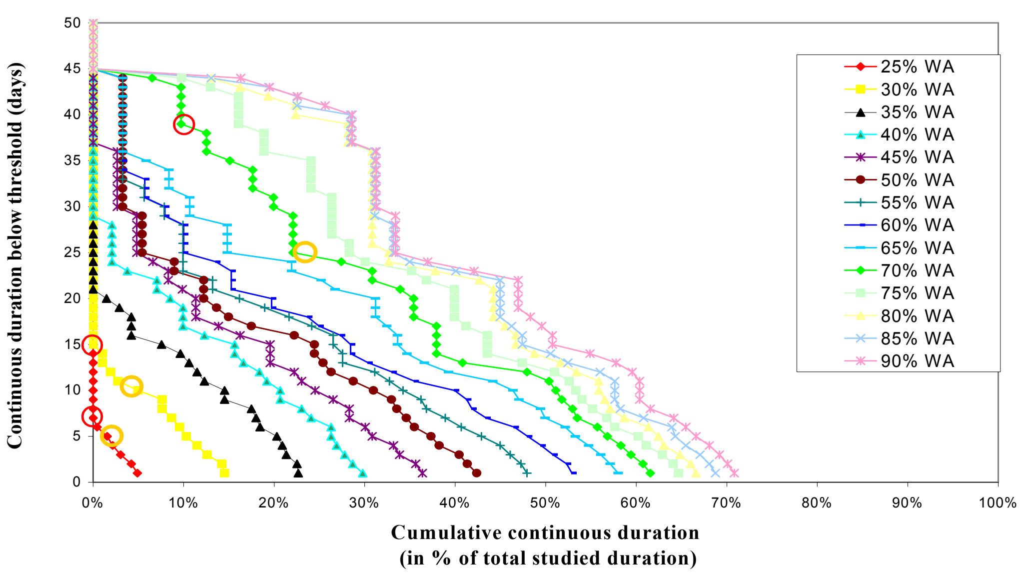


Figure 13: HDC and UCUT curves for Reach 2 American shad spawning.

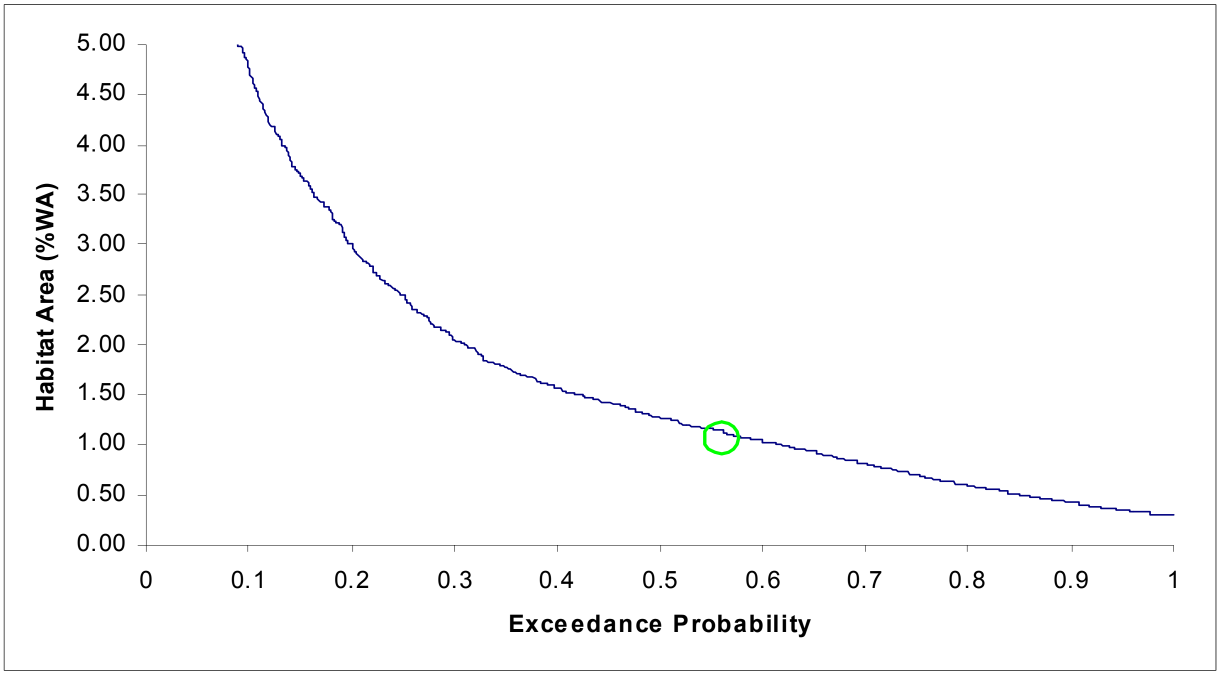
Figure 14 presents HDC and UCUT curves for reach 5, which represent American shad spawning habitat in the Lower Souhegan River. In reach 5 there is no clear inflection point on the HDC for *rare* habitat conditions, but the UCUT curves show a change in frequency of habitat events when the threshold moves from 35% WA to 40% WA. The *common* threshold was identified with 80% WA by a change of frequencies between habitat events observed on the UCUT curves.

For *rare* habitat duration we selected 5 days for allowable habitat duration. The catastrophic duration begins where the curve moves very close to the x-axis and was selected at 10 days. The UCUT for a *critical* event has an inflection point at 5 days and a catastrophic duration of 10 days. For the *common* level the inflection points are estimated with 15 days for common durations and 25 days for a catastrophic duration.

GRAF spawning

Figure 15 presents HDC and UCUT curves for reach 2, which represent GRAF spawning habitat in the Upper Souhegan River. In reach 2 there is a weak inflection point on the HDC for rare habitat conditions that corresponds with the position of 5% WA threshold on the UCUT curve diagram, which shows a change in the frequency of habitat events when the threshold is set at 10% WA. The *common* threshold was identified by the inflection point at the HDC with 30% WA.

We selected the 10 days for allowable habitat durations under the *rare* threshold. The catastrophic duration begins with 7 days. The UCUT for a *critical* event has a pronounced inflection point at 10 days and a catastrophic duration of 20 days. For the *common* level the inflection points are estimated with 20 days for the *common* duration and 27 days for a catastrophic duration.



May 1- June 15 , 1947 - 1977

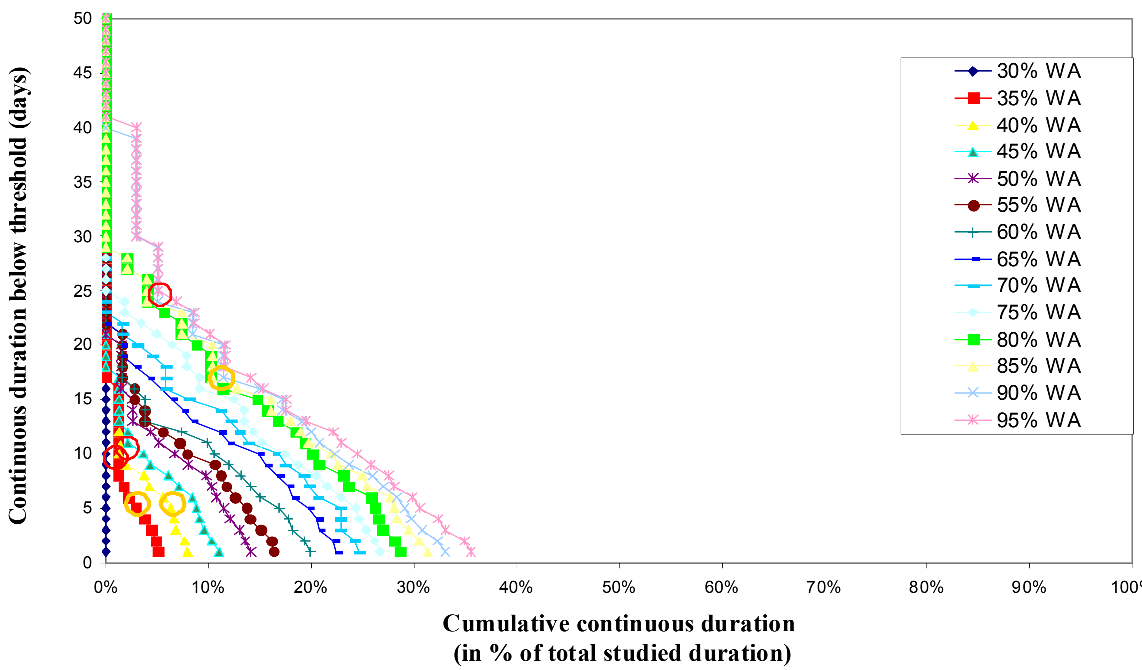
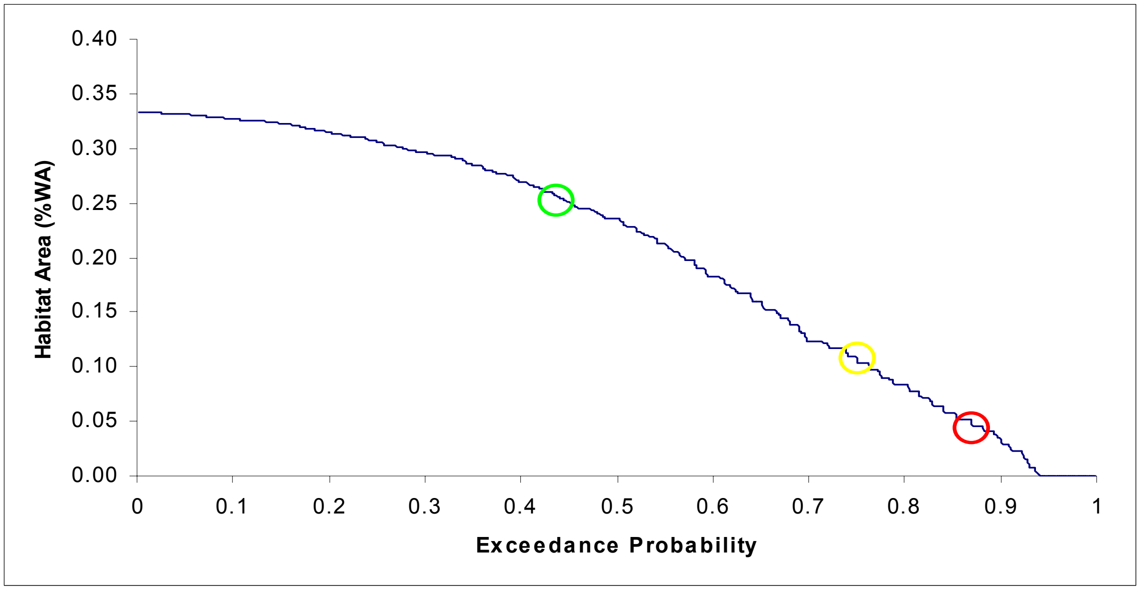


Figure 14: HDC and UCUT curves for Reach 5 American shad spawning.



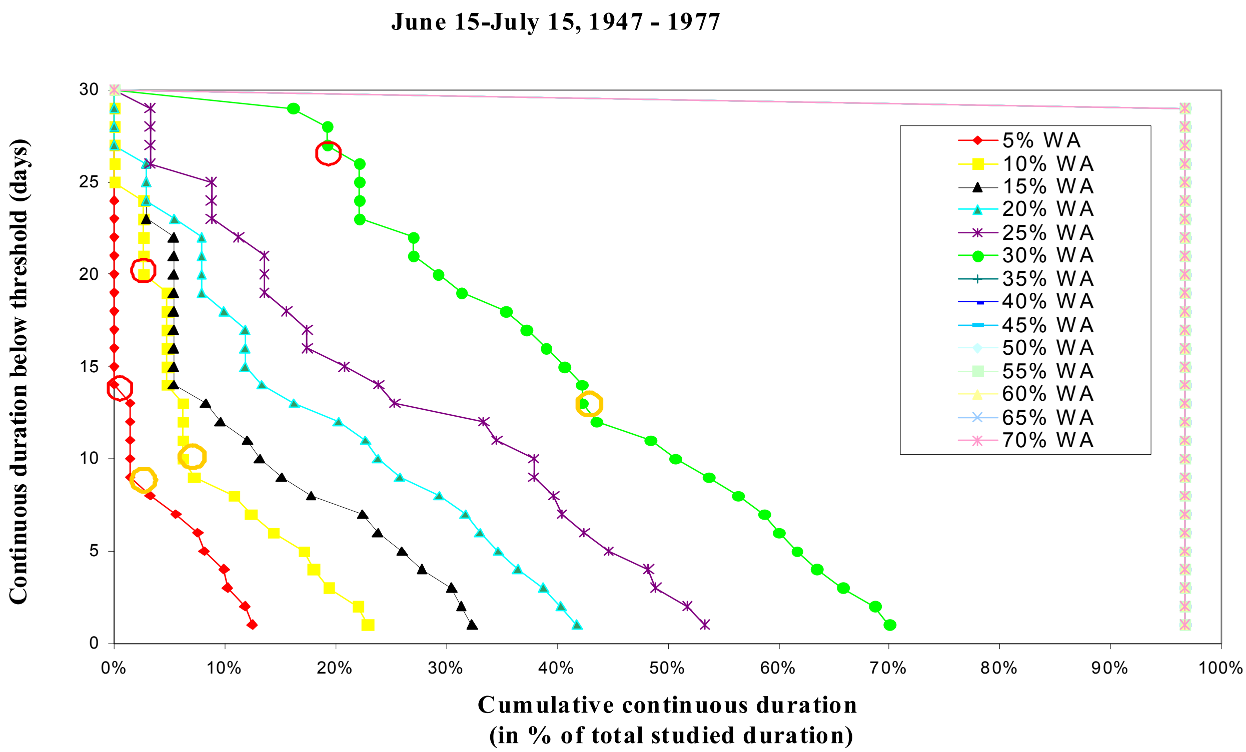
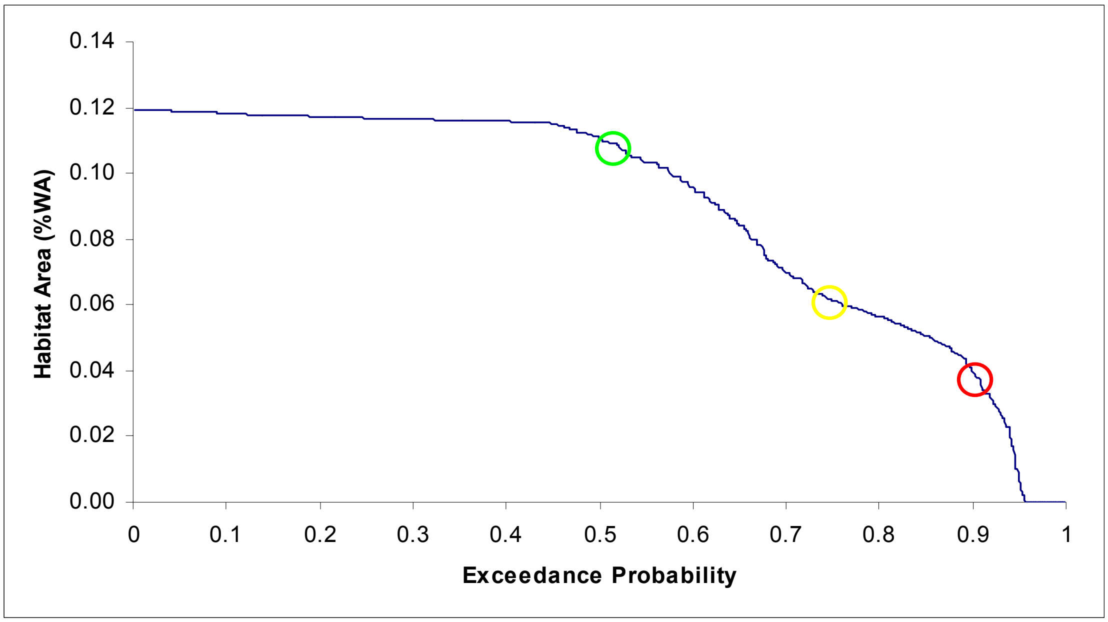


Figure 15: HDC and UCUT curves for Reach 2 GRAF spawning.

Figure 16 presents HDC and UCUT curves for reach 5, which represent GRAF spawning habitat in the Lower Souhegan River. In reach 5 there are very clear inflection points on the HDC for all habitat thresholds. The lowest inflection point corresponds with 4%

WA, which is also evident on the UCUT diagram. The frequency of events increases as the habitat threshold is set at 5%. The *common* threshold is identified with 11% WA.

For *rare* habitat duration we selected 10 days for allowable and catastrophic event durations. The UCUT for a *critical* event has an inflection point at 13 days and a catastrophic duration of 23 days. For the *common* level the inflection points were estimated with 17 days for common durations and 25 days for catastrophic duration.



June 15 - July 15, 1947 - 1977

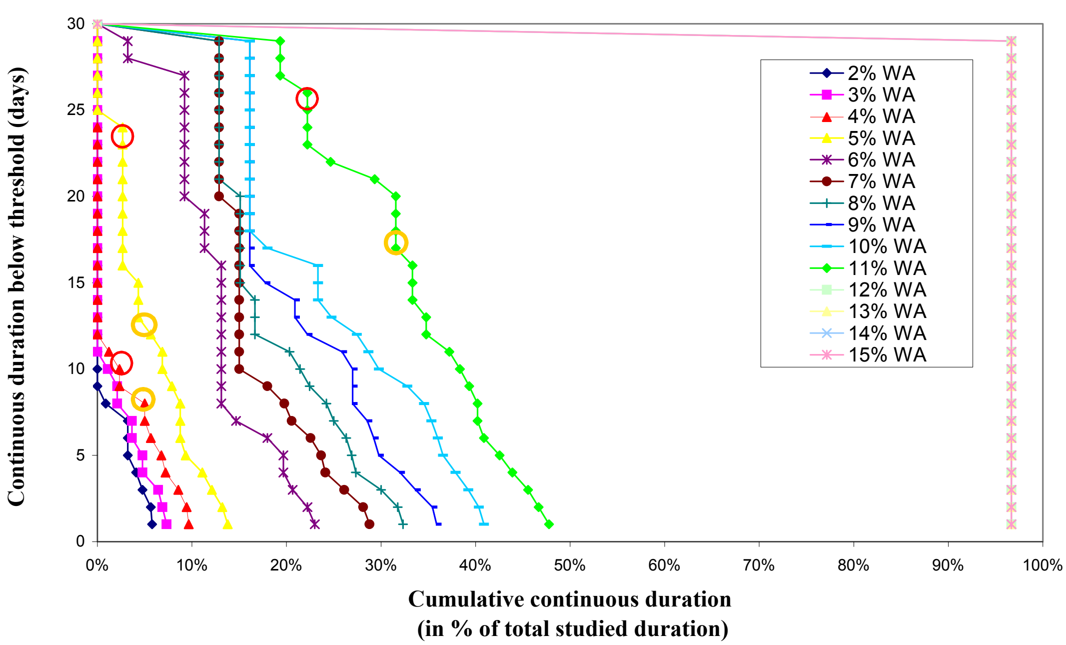


Figure 16: HDC and UCUT curves for Reach 5 GRAF spawning.

Discussion

The selection of habitat threshold for identified reaches and seasons appeared to be not very exact as it strongly depends on the morphological quality of the reach and the accuracy of applied hydrographs. One of the most difficult tasks was to identify thresholds for reach 3, for which the simulated hydrograph was remarkably different from the hydrographs for other locations. Therefore, we have the least amount of confidence in the values for this reach. For the determination of protective summer flow patterns in the Upper Souhegan we propose to use the criteria from the other two reaches. For both reaches (1 and 2) the thresholds were good and distinguishable, but reach 1 required higher proportions of wetted area and higher flows to be suitable. In reaches 4 and 5 the significant thresholds were also clearly visible, but in reaches 6 and 7 the identification of the thresholds was slightly more complicated, due to very subtle inflection points on the UCUT curves.

During the Atlantic salmon spawning season the significant thresholds of *rare* and *critical* habitat events were apparent, but the *common* threshold was much harder to define. The flow based UCUT's for the overwintering seasons have scarcely any inflection points and we have a low amount of confidence in the values for allowable and catastrophic durations.

During American shad spawning, reach 2 displays the group of *rare*, *critical* and *common* habitat events can be distinguished well for the Upper Souhegan. A high concentration of UCUTs in the lower left corner of the graph made the selection of thresholds for Lower Souhegan more complex. This phenomenon is due to the high frequency of high flows in this season. The habitat thresholds for resident species spawning were well identified, although the allowable durations were more difficult to determine in the Lower Souhegan. It needs to be considered that in this season higher flows limit habitat as much (or more) as very low flows.

The flows corresponding with above habitat thresholds are determined from habitat rating curves and presented in main report.